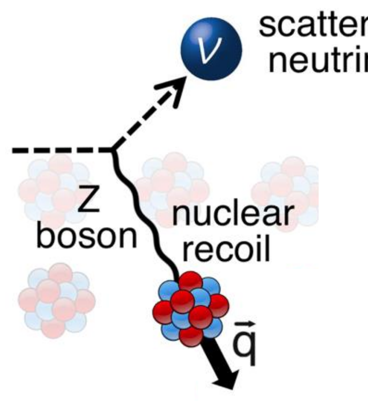
The RED-100 experiment on CEνNS study

E.S.Kozlova, NRC “Kurchatov Institute” – ITEP & NRNU MEPhI
on behalf of RED collaboration

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS):

$$\nu + A \rightarrow \nu' + A'$$



In 1973, a neutral current has been discovered in weak interactions:
Observation of neutrino-like interactions without muon or electron in the Gargamelle neutrino experiment.
Phys. Lett. B 46, 138–140 (1973).

In 1974, the idea of coherency at small momentum *q* transferred to a nucleus (*qR*<<1, where *R* is a size of nucleus) :
D.Z. Freedman, Coherent effects of a weak neutral current, Phys. Rev. D 9 (1974) 1389.

For heavy nuclei, CEνNS starts playing role when the neutrino energy **≤ 50 MeV**

The process hasn’t been observed during more than 40 years (**until the discovery by COHERENT in 2017**) because of technical difficulties: the energy deposition in a detector produced by nuclear recoils is in keV region, and the detector mass must be significant: several kg or more.

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS):

The differential cross section is described by formula:

$$\frac{d\sigma}{dE_r} = \frac{G_F^2}{4\pi} Q_w^2 M \left(1 - \frac{ME_r}{2E_\nu^2}\right) F^2(Q^2),$$

where G_F is Fermi constant, $F(Q^2)$ is nuclear formfactor Q is four-momentum, $Q_W = N - (1 - 4\sin^2(\theta_W))*Z$ is a weak charge of nucleus with N neutrons and Z protons, θ_W is Weinberg angle.

Since $\sin^2(\theta_W) \approx 0.25$, $\sigma \sim N^2$.
For heavy nuclei (Xe, Cs, I), $\langle\sigma\rangle \approx 7 \cdot 10^{-41}$ cm^2 averaged over the energy spectrum of reactor antineutrinos.

The process plays very important role in astrophysics (supernova dynamics).

If the cross section differs from the predicted one, this may be an indication of “new physics”.

The possible practical application is nuclear reactor monitoring.

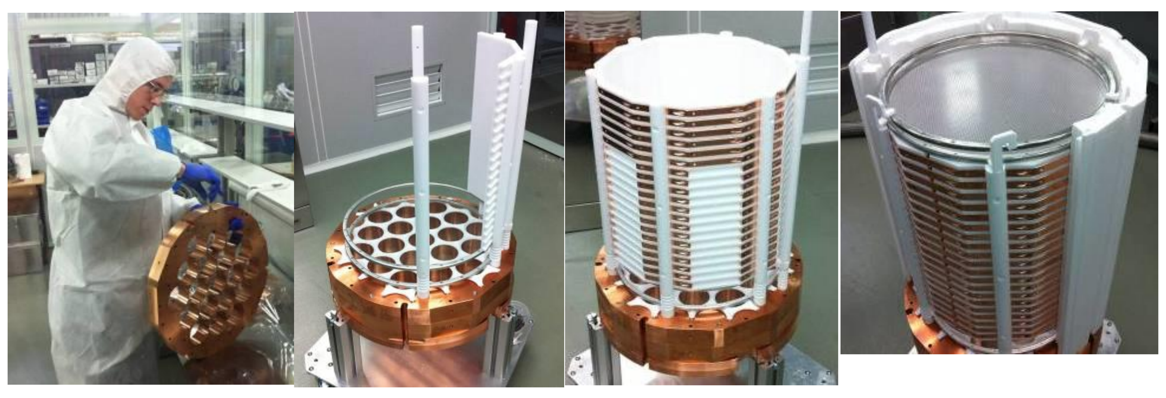
The CEνNS process has not been observed yet for the low-energy antineutrinos from a nuclear reactor!

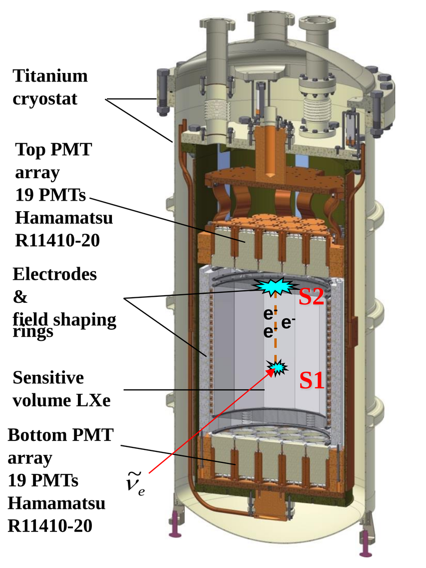
RED-100 detector

RED-100 is a two-phase noble gas emission detector.

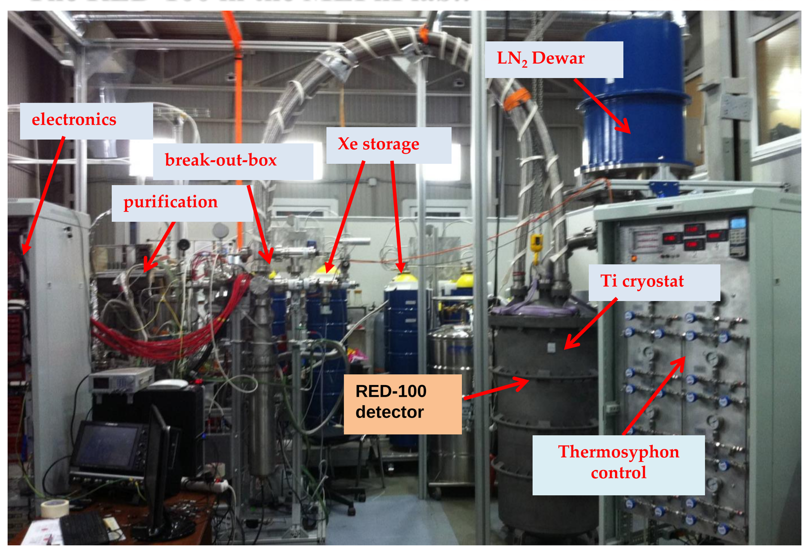
Contains ~200 kg of LXe, ~100 kg in FV (Fiducial Volume).

The sensitive volume ~ 36 cm in diam., ~ 40 cm in height, is defined by the top and bottom optically transparent mesh electrodes and field-shaping rings.



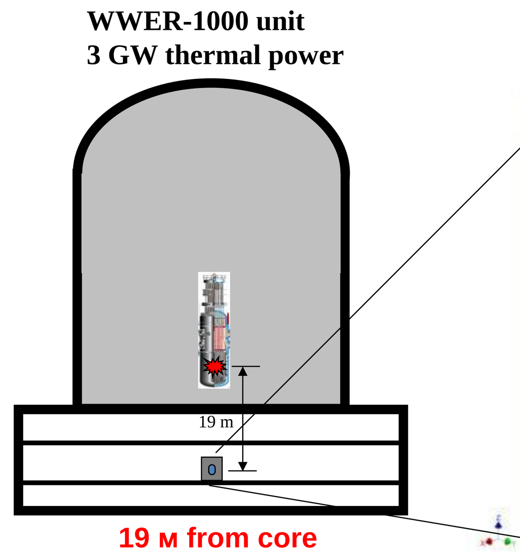


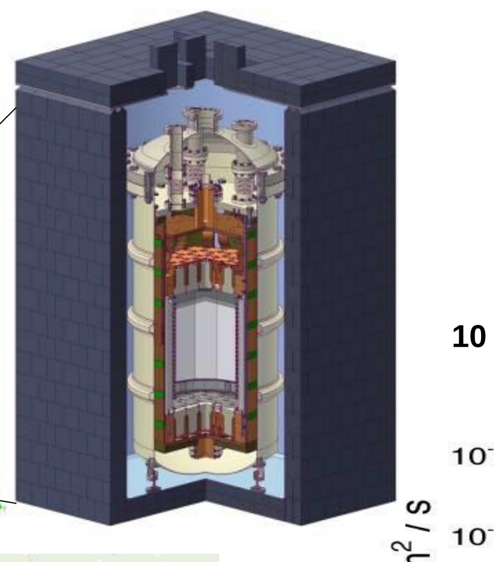
The RED-100 in the MEPhI lab.: 1-st technical run Mar



RED-100 detector @ Kalinin NPP

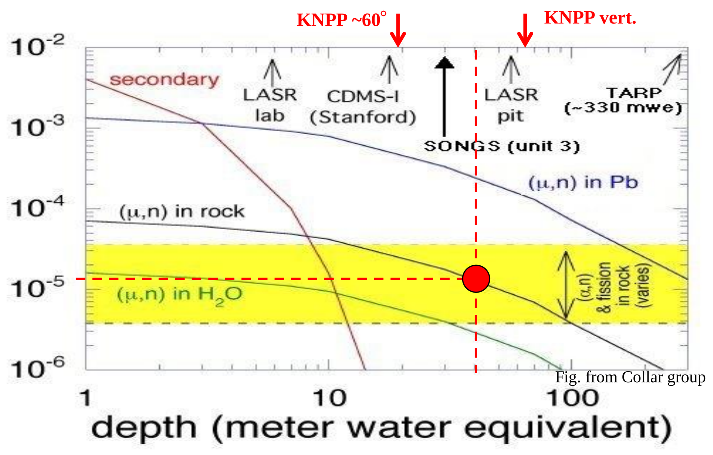
WWER-1000 unit
3 GW thermal power





Φ_ν *@19m ~ 1.3·10*^{13} *cm*$^{-2}$*s*$^{-1}$

γ and n shield:
10 ÷ 15 cm Pb + ~15 cm H_2O

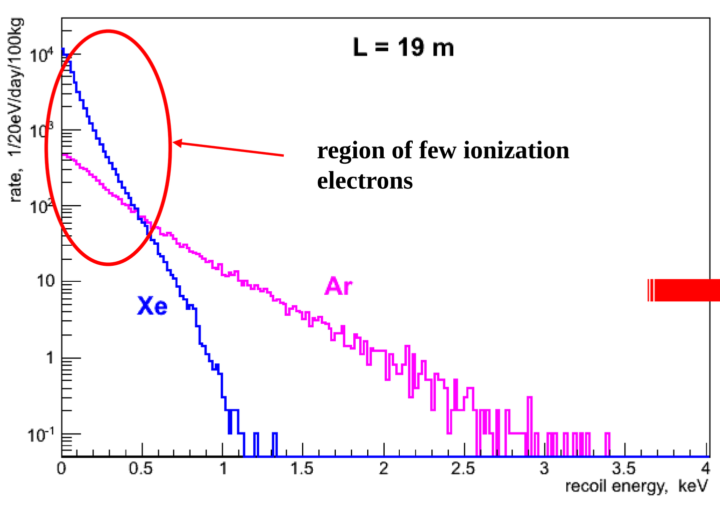


The building and the reactor is a good shield from muons and n-component of cosmic rays

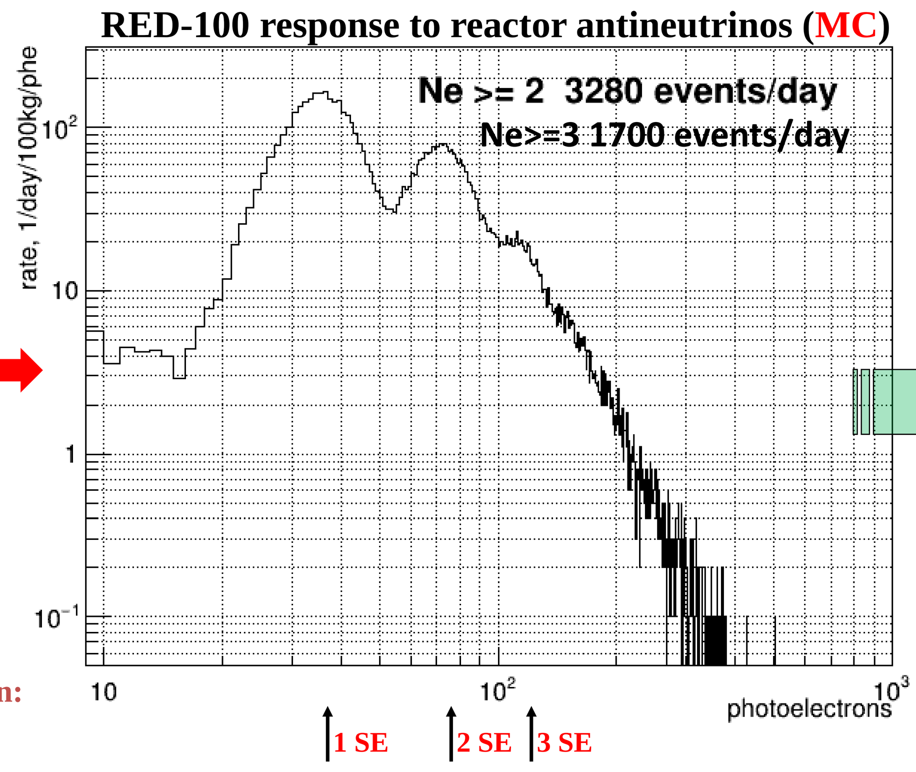
Expected signal in RED-100 from nuclear recoils for the reactor antineutrinos (CEνNS process).

L=19 m; 3 GW thermal power

Nuclear recoil (Xe&Ar) energy spectrum for reactor antineutrinos



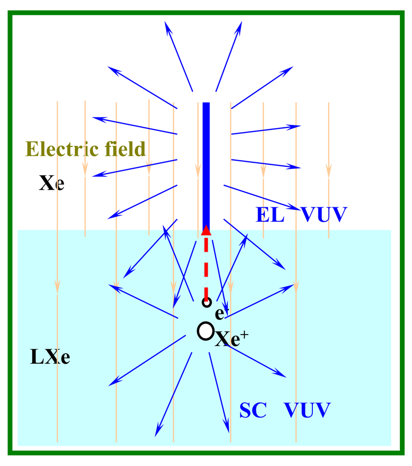
RED-100 response to reactor antineutrinos (MC)



A two-phase noble gas emission detector (with EL amplification) is sensitive to the very small ionization: single ionization electron (SE) can be detected

Threshold between 1 and 2 SE corresponds to ~ 250 eV

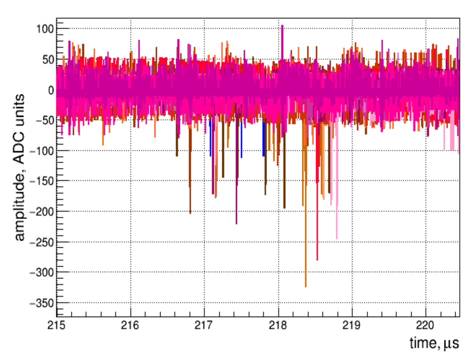
RED-100 performance: single electron (SE) is a very important characteristic of a two-phase detector.



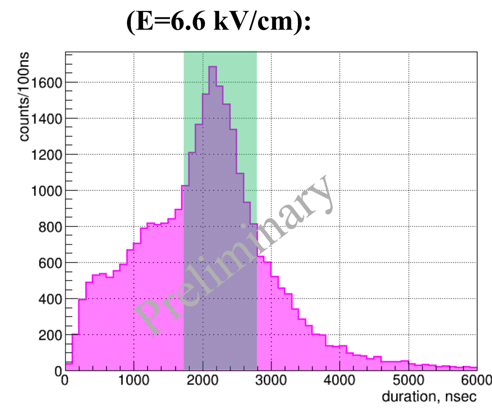
Each ionization electron extracted by electric field to the gas phase emits HUNDREDS electroluminescent (EL) photons (in VUV range).

The number of single photoelectrons (SPE) per SE is defined by the light-collection efficiency. Typical value of SPE/SE for two-phase detectors is SEVERAL TENS.

Example waveform of SE :

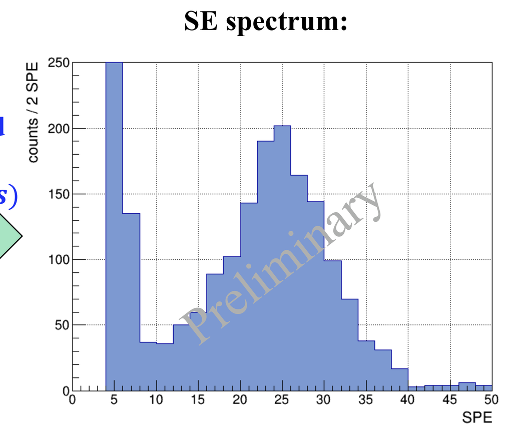


SE duration distribution (E=6.6 kV/cm):

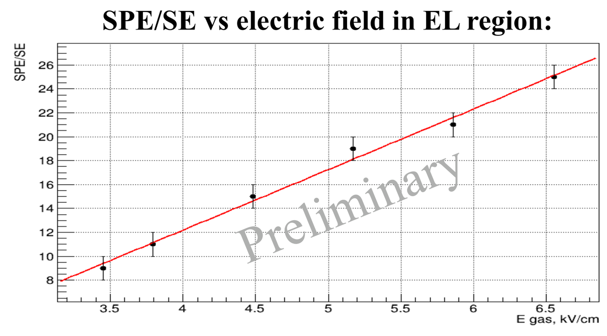


For selected interval (1.7 – 2.8 μs)

SE spectrum:



SPE/SE vs electric field in EL region:

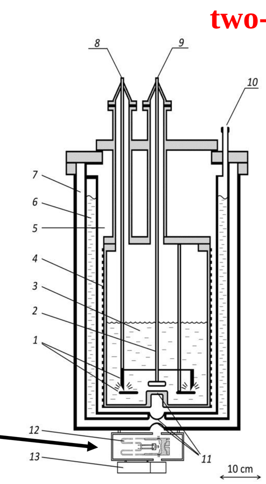


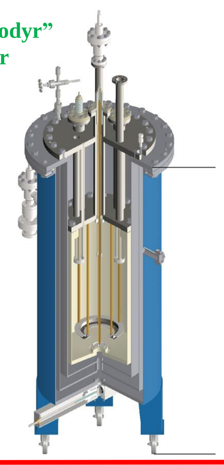
Test at a ground-level laboratory without passive shield:
1SE rate ~ 10 kHz
2SE rate ~ 10 Hz
3SE rate ~ 10^{-2} Hz (~ 10^3 day^{-1})

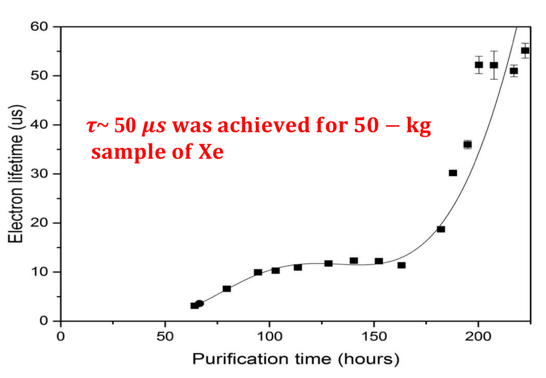
RED-100 performance: LXe purity

Electron lifetime of free electrons before capture by electronegative impurities is one the most important parameters of a two-phase detector

Liquid Xenon was purified by a spark-discharge method with “Mojdodyr”:
D.Yu. Akimov et al., Instrum. Exp. Tech. 60 (2017) no.6, 782



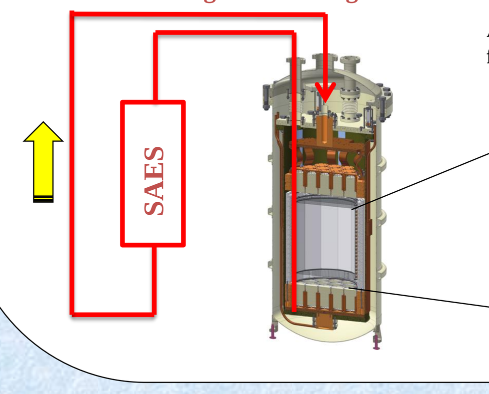




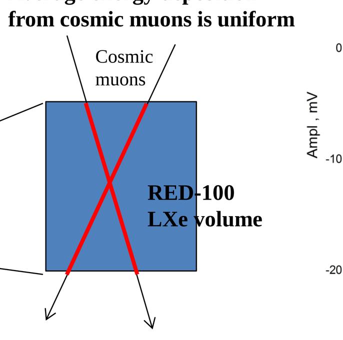
Then, ~ 250 kg of Xe was purified in Nov 2017; τ ≥ 50 μs was achieved !

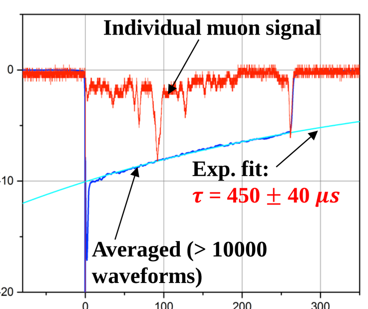
1st technical run Mar 15 – Apr 27

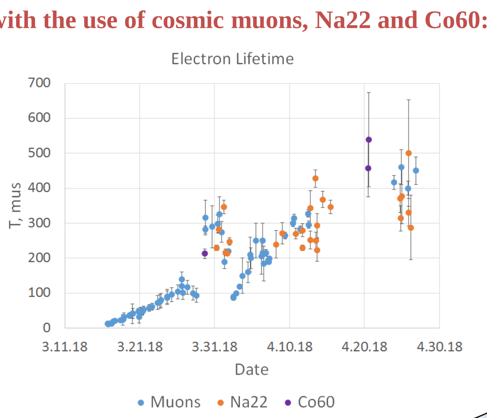
Final purification was done by constant circulation through the SAES getter:



Electron lifetime was measured periodically during the run with the use of cosmic muons, Na22 and Co60:







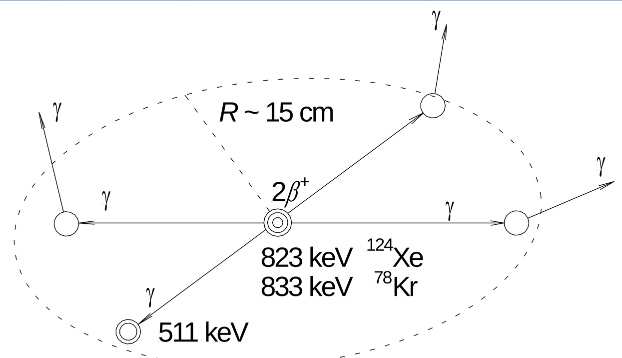
Search for double beta decay of ^{124}Xe and ^{78}Kr isotopes

$$2\beta^+0\nu: \quad {}^{124}_{54}Xe \rightarrow {}^{124}_{52}Te + 2e^+ \qquad {}^{78}_{36}Kr \rightarrow {}^{78}_{34}Se + 2e^+$$

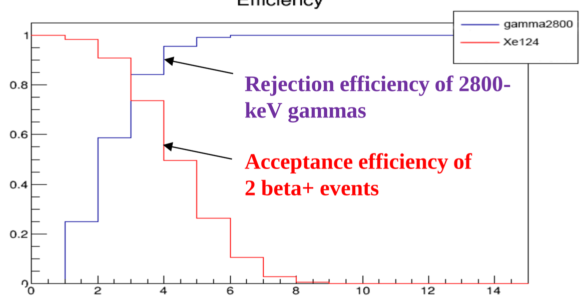
$$2\beta^+2\nu: \quad {}^{124}_{54}Xe \rightarrow {}^{124}_{52}Te + 2e^+ + 2\nu \qquad {}^{78}_{36}Kr \rightarrow {}^{78}_{34}Se + 2e^+ + 2\nu$$

	Nat. abund.,%	Q= M(A,Z)–M(A,Z–2), keV	$T_{1/2}$ theor., years * $2\beta^+0\nu$	$2\beta^+2\nu$	$T_{1/2}$ experim., years ** $2\beta^+0\nu$	$2\beta^+2\nu$
^{78}Kr	0,355	2846,3±0,7	(1.0 – 1.7) × 10^{28}	(4.94–15.8) × 10^{25}	> 2 × 10^{21}	
^{124}Xe	0,0952	2865,4±2,2	(2.3–7.7)×10^{28}	(1.7–38)×10^{26}	>4.2·10^{17}	>2.0·10^{14}

* PhysRevC**87**(2013)034318; J. Phys. G**40**(2013) 075102
** PhysRevC**50**(1994)1170; PhysLettB223(1989)273

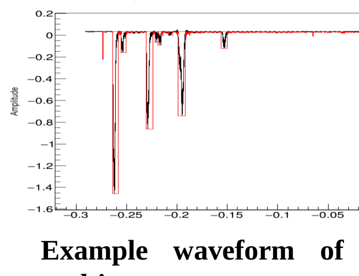


2 beta+ event must have larger multiplicity than gammas with the same energy (~ 2800 keV)
Gamma bckg can be rejected at a trigger stage by threshold on multiplicity (MC simulation):

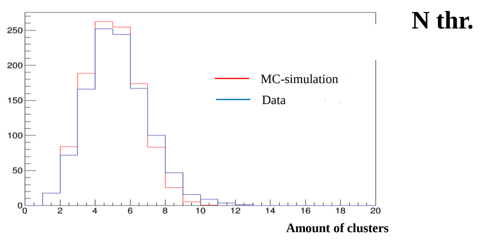


The event of 2 beta+ event must have the very unique signature:
- **the central vertex from 2 positrons and**
- **four 1-st points of interaction of 511-keV annihilation gammas**
- **all of them are in one plane**

^{78}Kr can be added to LXe in amount of ~1 kg



Example waveform of multi-vertex event (DAQ triggered when total EL length > 16 μs):



Amount of 2-beta candidates clusters